II.4 Thermally Integrated High Power Density SOFC Generator

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Subcontractors: Versa Power Systems, Des Plaines, Illinois (GTI, MSRI, UU)

Objectives

Research and development in Phase I shall focus on the research, design and manufacture of a planar solid oxide fuel cell (SOFC) power generator for stationary applications (3-10 kW) using natural gas as the standard fuel. Goals of the Phase I project include:

- Design of a thermally integrated, internal reforming fuel cell stack and compact balance-of-plant (BOP) package and system.
- Development of optimal cell structure having the target power density (300 mW/cm^2) and durability at lower operating temperatures (≤800°C).
- Development of fuel processing system for operation on U.S. natural gas as the baseline fuel and initiation of development of fuel processing systems for broadly available fuels such as diesel.
- Prototype testing of natural gas (baseline fuel) fueled unit meeting the minimum Solid State Energy Conversion Alliance (SECA) technical requirements.

Approach

The research and development to achieve the above goals is organized in the following tasks:

- **System Design & Analysis** – In this task, work shall focus on prototype design, system-level modeling and analysis. Work will also concentrate on fuel processor subsystem development and thermally integrated power system development.
- **Cell Design, Development and Optimization** – In this task, work shall focus on improvements in cell performance through material changes and refinements. Composition and morphology of the anode, electrolyte, and cathode will be addressed to increase cell performance. Thermo-mechanical modeling of cells will be performed.
- **Stack Design and Development** – In this task, work shall focus on the development of 3-10 kW stack design to resolve manifold design and stack thermal issues and improve stack performance. Focus of work will be on the internal reforming stack design.
- **Product Development and Packaging** – Work shall concentrate on the integration of SOFC subsystems (electrical BOP and mechanical BOP) with SOFC stacks to maximize electrical efficiency and to reduce heat losses, overall system weight, and cost.
- **Process Development for Cost Reduction** – Work shall focus on SOFC cost reduction by manufacturing process improvements and adaptation of mass production techniques.
- **Prototype Test and Evaluation** – Work shall focus on the test and evaluation of the prototype system against the minimum SECA technical requirements.

Accomplishments

- In an endurance cell test using FCE's direct fuel cell (DFC) hardware, the internal reforming efficiency of methane fuel was over 95% with excellent stability (7000 hours of operation).
- The highest power density of 1.9 W/cm^2 at 800°C on button cell and 1.4 W/cm^2 at 750°C on 10 x 10 cm cell on hydrogen fuel (ideal conditions) has been achieved.
- An 80-cell tower, assembled using 4 stacks, produced 3.5 kW DC power.
- A kW-class SOFC system was designed, built and operated on natural gas fuel with a net system efficiency of up to 35%.

Future Directions

- Complete 3-kW baseline system design for natural gas fueled SOFC and initiate 10-kW advanced system design.
- Optimize electrode functional layers.
- Reduce cell operating temperature to 700°C.
- Validate alternate fabrication processes to improve cell performance and reduce cost.
- Develop high power density stack design incorporating modeling results, and advance gaskets and internal reforming cell design.

Introduction

The FCE team has initiated its technology development efforts. The efforts in this period focused on the critical technology development areas to meet the SECA program goals for the 3-10 kW SOFC generator. The FCE team has made significant progress in cell, stack and system technology areas and has met all planned milestones. In addition, the Team, FuelCell Energy and subcontractors, Versa Power Systems, including Gas Technology Institute (GTI), Materials and Systems Research, Inc. (MSRI) and University of Utah (UU), has developed and integrated a strategic R&D plan, milestones and efforts to ensure the achievement of SECA goals.

Approach

The FCE team is focusing on developing a 3-10 kW planar, thin-film, anode-supported SOFC system operating at 700°C, with a power density of >0.5 W/cm^2 at 0.7 V/cell by Phase III. The Phase I effort will focus on development of cell and stack designs, leading to a prototype 3-10 kW system operating on natural gas fuel, with lower heating value efficiency target of up to 40% and a degradation rate of <2%/1000 hours.

The cell technology approach is based on the record-setting performance achieved by MSRI and FCE. The baseline cell materials will be Ni/YSZ cermet for anode, yttria-stabilized zirconia (YSZ) as electrolyte and lanthanum strontium manganite (LSM) or other ceramic for cathode. In the stack design, internal and external manifold designs will be evaluated, innovative seal designs will be adopted, and internal reforming combined with radiative and convection cooling will be developed. A 3-kW baseline system and an advanced 10-kW system will be developed using the kW-class system under development within the FCE team.

Results

Cell Development: Cell development was focused on intermediate-temperature (700-750°C), planar, anode-supported SOFC technology. Significant progress in cell materials, design, scale-up, and fabrication has been made. Performance of SOFC trilayer (positive electrolyte negative) was improved significantly by improving the functional layer design. The highest power density of 1.9 W/cm^2 at 800°C on button cell and 1.4 W/cm^2 at 750°C on 10 x 10 cm cell on hydrogen fuel was achieved. Internal reforming of methane to hydrogen is a key to high power density cell operation. An internal reforming cell (100 cm^2 area) was assembled using

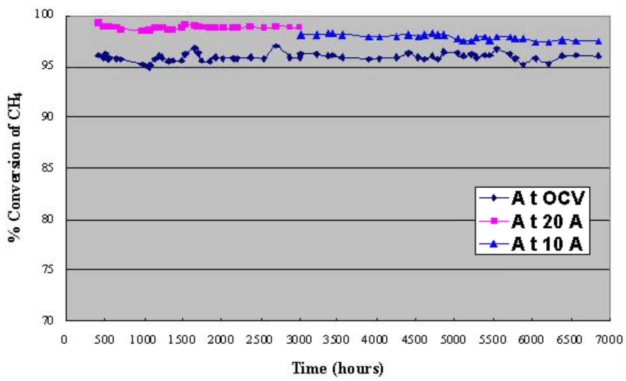

Figure 1. Stability of Internal Reforming of Methane - Excellent Stability of Internal Reforming

FCE's DFC hardware. The cell exhibited good reforming efficiency (>95% at 700°C) and excellent stability during 7000 hours of operation (Figure 1). As expected, the internal reforming efficiency increased as the operating current increased.

Conventional SOFC cell (trilayers) manufacturing requires multiple firing steps. These steps are complex, requiring elaborate process control and expensive equipment. FCE's single-fire process offers a significant cost savings. The single-fire trilayer processing technology was improved with greater reproducibility in performance. Cell sizes fabricated ranged from button size up to 20 x 20 cm. The cell and stack test results successfully validated the viability of the process.

Stack Development: The SOFC stack design was scaled up from 5 to 20 cells per stack, incorporating larger area (120 cm^2) cells. Figure 2 shows a 20-cell stack, which is comprised of commercially available materials with matched thermal expansion coefficients. The individual cells of a 20-cell stack at 750°C and 0.5 A/cm^2 exhibited excellent performance. The average cell voltage was 0.85 V with a voltage spread of less than 20 mV. An 80-cell tower consisting of 4 stacks of 20 cells each was built and tested. This 4-stack tower produced 3.5 kW DC power after conditioning. Thermal cycling capability of two 20-cell stacks was validated through five thermal cycles each.

Seal technology is the key area for stack development to meet the SECA goals. Several gasket materials and designs, such as mica, glass and

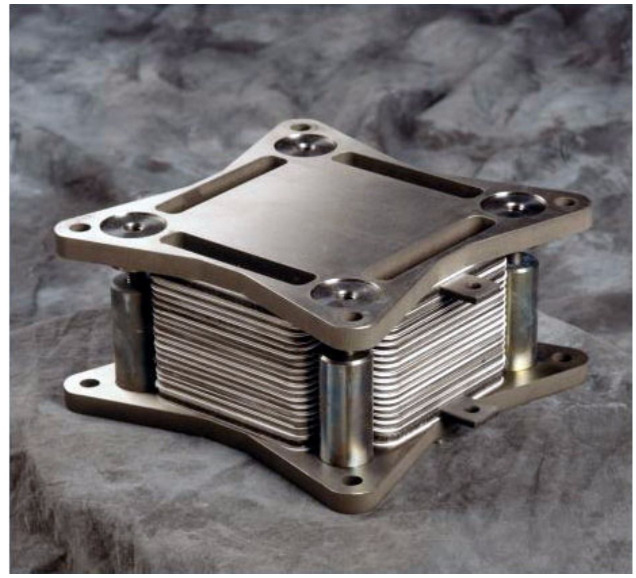

Figure 2. 20-cell SOFC Stack - This Stack Is a Building Block for an 80-cell Tower

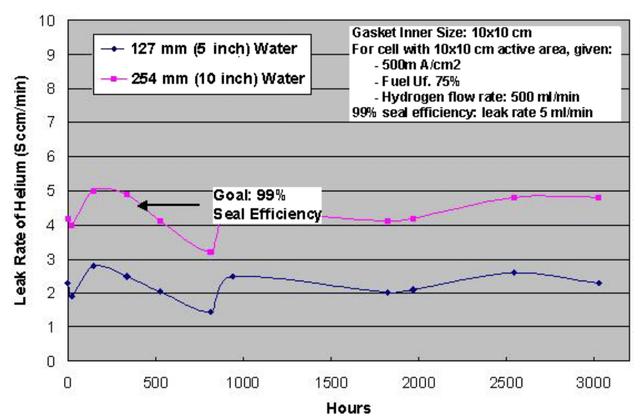

Figure 3. Gasket Development Test Results - The 3000-hour Test Showed Acceptable Seal Performance

other composite materials, were identified, and their evaluation was initiated. A new composite gasket, PH-1 gasket, was developed using FCE's DFC technology as a foundation and showed very promising results. For gaskets with inner perimeter 10 cm x 4 cm, the leak rates were 2-3 ml/min for air and 6-7 ml/min for simulated helium at backpressure of 15 inches water, only about a sixth that of a mica gasket with the same size. Over 3000 hours endurance testing of PH-1 on simulated fuel side, operation indicated excellent seal performance, as shown in Figure 3.

Figure 4. 2-kW Aurora System

System Development: Preliminary design of baseline 3-kW system was initiated. The design is based on FCE's 2-kW Aurora system with technical input from the parallel California Energy Commission project. The system will be natural gas fueled and operate in a grid parallel mode. It will incorporate a room temperature desulfurizer for natural gas. The advanced system (10 kW) will incorporate features to further reduce system cost. Such features may include anode recycle (hot, cold or selective), dual voltage output (DC and AC) for telecom applications, low-cost cell and stack designs, etc.

Figure 4 shows the prototype Aurora system. It incorporates significant design advances in thermal integration and management and power conditioning. Segregation of the heat sources (stacks and afterburner) has been accomplished through the creation of two physically separate zones. The stack zone has a single 80-cell stack tower at its center with other components located in close proximity to the vertical faces of the stack. The integrated module zone exchanges heat from the afterburner to the prereformer and other regenerative exchangers. With this design, heat flows in the system can be varied and directed to specific components, allowing for maximum operational control and thermal management of the system. The result is a system with the capability to operate with higher fuel utilization, as well as a significantly higher level of electrical and cogeneration efficiency. In addition to the advances in performance, the system has also been designed to facilitate maintenance with quickly replaceable modules. The test results on natural gas fuel showed that a peak electrical efficiency of up to 35% is feasible with this system.

Conclusions

- The technology development of the planar SOFC cell, stack and system indicate that the higher power density (300-500 mW/cm^2) operation is facilitated by internal reforming. FCE's internal reforming technology was validated through a 7000-hour cell test.
- The 80-cell tower concept using 4 stacks of 20 cells each offers a low-cost, near-term option to build 3-10 kW size SOFC systems.

Publications

1. P. Patel, Thermally Integrated High Power Density SOFC Generator, SECA Annual Conference, Boston, MA, May 11-13, 2004.

2. B. Borglum, Planar SOFC Development Status at FuelCell Energy, Solid Oxide Fuel Cell Forum, Lucerne, Switzerland, June 28 - July 2, 2004.